Search for Tensor Type Weak Currents by Measuring the β-asymmetry Parameter in Nuclear Beta Decay

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***Nuclear Physics Institute, Rez (Czech Republic)

Overview

- **Physics motivation :** Fundamental physics via correlation measurements in β-decay
- **Experimental techique :** Low Temperature Nuclear Orientation (LTNO)
- **Data analysis :** Extracting Ã from the β-anisotropy with the the help of GEANT4 Monte Carlo simulations
- **Results :** The β-asymmetry parameter of ^{60}Co and ^{114}In
- **Future plans and conclusions**

Physics motivation : Correlation measurements in nuclear beta decay to probe the weak interaction Hamiltonian

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β-decay in the Standard Model:

- Weak interaction at low energies : handron x lepton current interaction
- Fully parity violating Vector – Axial-Vector interaction ($C_{V,A}/C'_{V,A} = 1 \quad |C_A/C_V| \cong 1.26$)

Most general Lorentz invariant form:

- $H_\beta = H_V(C_V, C'_V) + H_S(C_S, C'_S) + H_A(C_A, C'_A) + H_T(C_T, C'_T)$

? Time Reversal Violation ? Right Handed Currents ? Scalar or Tensor Interactions

Current limits from β and neutron decay of the order of 5% to 10% *

Correlation measurements to probe H_β:

$$\omega\left(\langle \vec{J} \rangle, \vec{\sigma} \,\middle|\, E_e, \Omega_e\right) dE_e\, d\Omega_e = \omega_0 \times \xi \left\{ 1 + b\frac{m}{E_e} + \frac{\vec{p}_e}{E_e}\left(A \frac{\langle \vec{J} \rangle}{J} \right) + a\frac{\vec{p}_e \cdot \vec{q}}{E_e E_\nu} + \ldots \right\}$$ **

* N. Severijns et. al. , Rev. Mod. Phys., **78** , 991 (2006)

** J.D. Jackson et al. , Nucl. Phys. 4 (1957) 206

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Measuring the correlation between the nuclear spin and the momentum of the β-particle

$$W(\theta) = \frac{\omega(\vec{J})}{\omega(\vec{J}=0)} = 1 + \tilde{A}\frac{\langle \vec{J} \rangle}{J}\frac{p_e}{E_e}$$

$$\text{with } \tilde{A} = \frac{A}{1 + b\dfrac{\gamma m_e}{E_e}}$$

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$$\tilde{A}_{GT}^{\beta^\mp} \cong \lambda_{J'J}\left[\mp 1 + \frac{\alpha Z m}{p}\,\mathrm{Im}\left(\frac{C_T + C'_T}{C_A}\right) + \frac{\gamma m}{E_e}\,\mathrm{Re}\left(\frac{C_T + C'_T}{C_A}\right) \right]$$ ***

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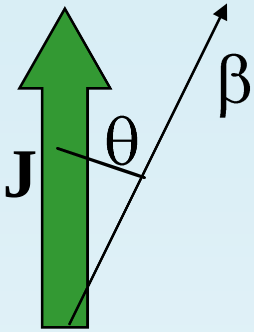
** J.D. Jackson et al. , Nucl. Phys. 4 (1957) 206

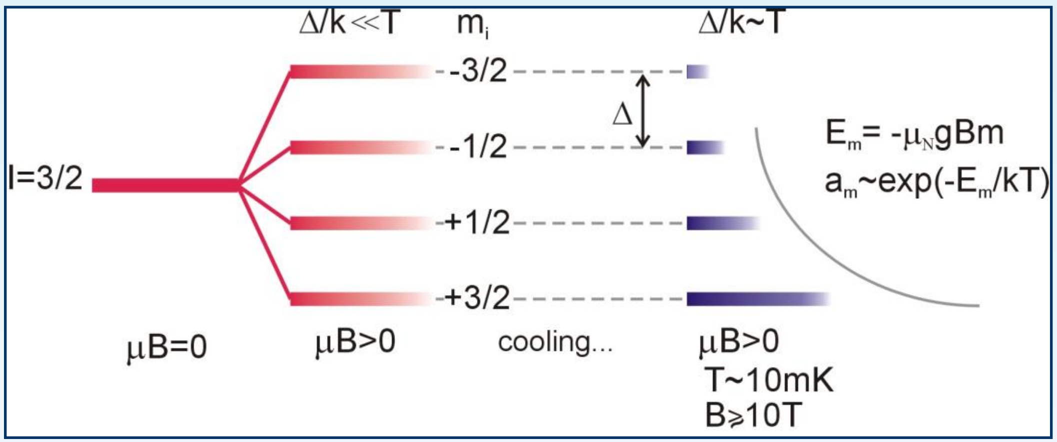
*** R. Hubert et. al. , PRL , **78** , 202301 (2003)

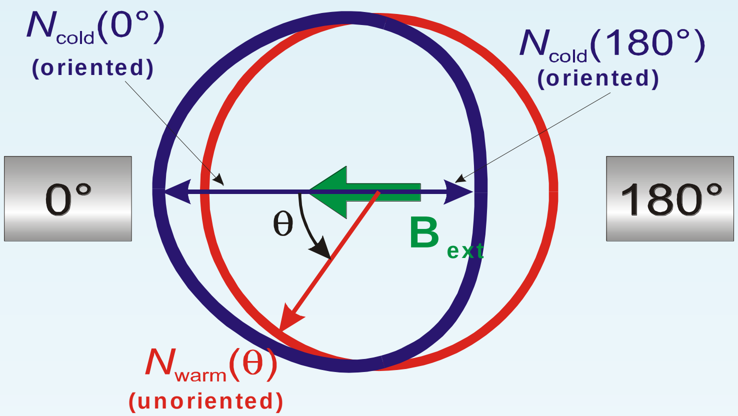
Experimental technique : Low temperature nuclear orientation



The angle between the impuls of the β-particle and the nuclear spin has to be under control. → Create on oriented ensemble of nuclei with LTNO

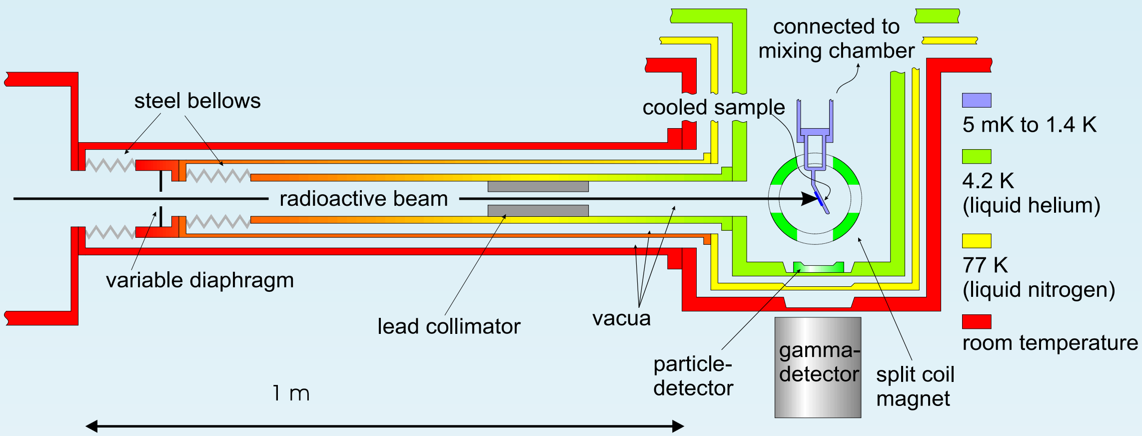
(MOT + Lasers , Vieira et. al, Hyperfine Int. 127,387)





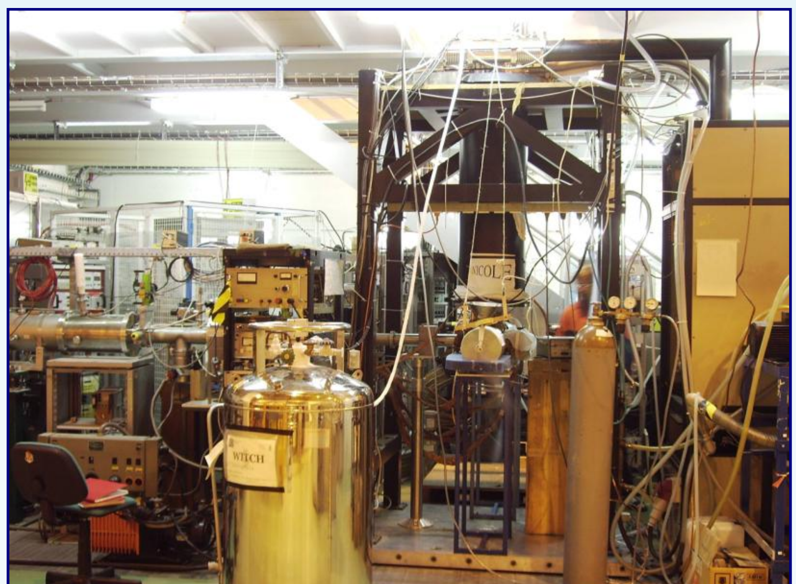
- ^3He-^4He dilution refrigerators
- Pure implantation foils with smooth surface
- Superconducting magnets
- Particle detectors operating in high magnetic fields and at low temperatures

Experimental technique : Low temperature nuclear orientation



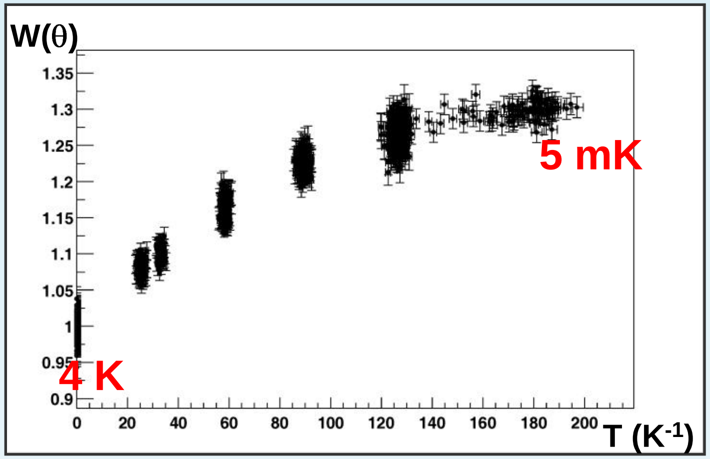
Hight Field setup (Leuven)

Online setup (ISOLDE/CERN)



Data Analysis: Extracting Ã from the β-anisotropy with the help of GEANT4 Monte Carlo simulations

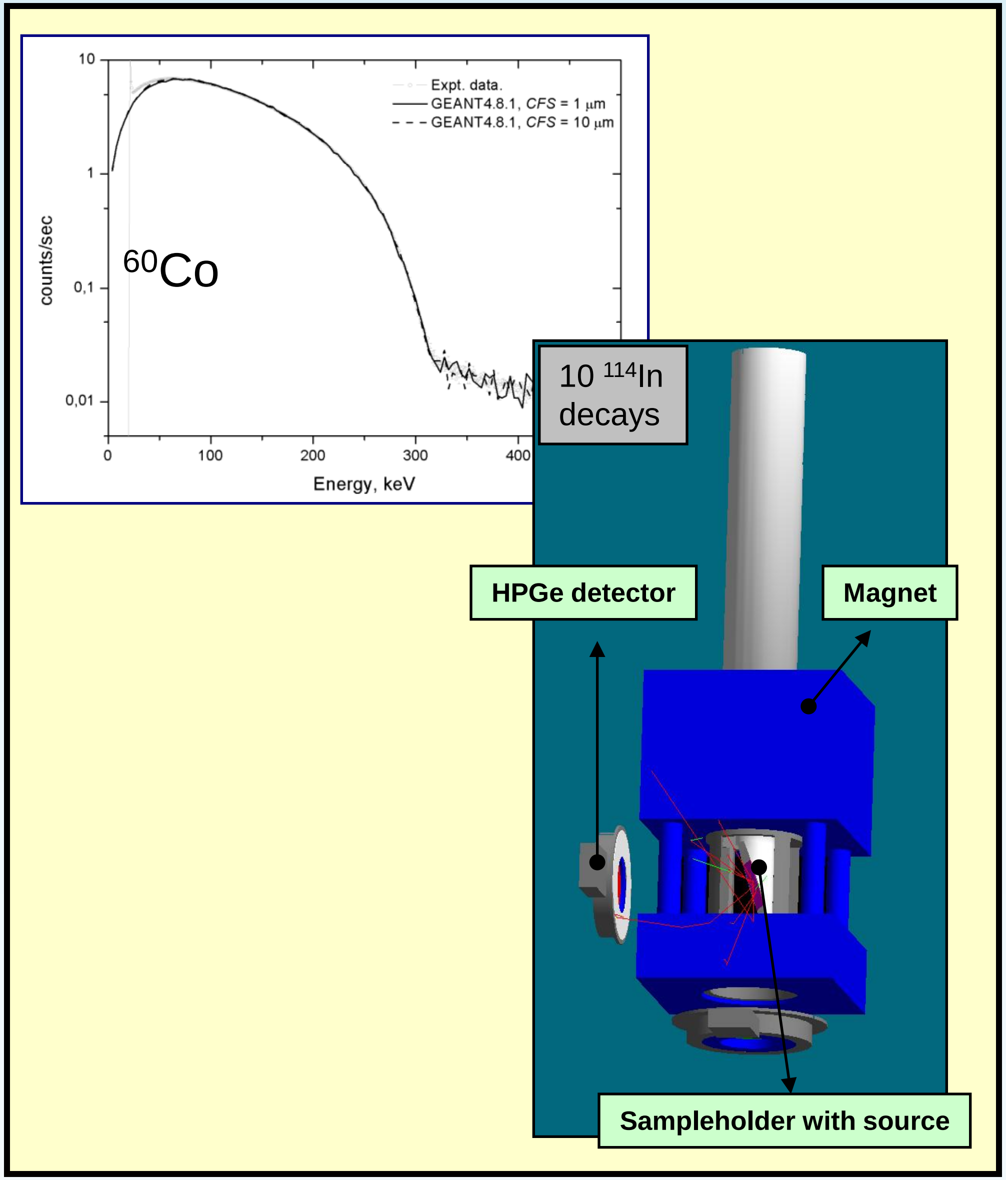
The data :



GEANT4 has to take care of scattering effects, energy loss, magnetic field effects, ... *

→ Test code for different experimental conditions

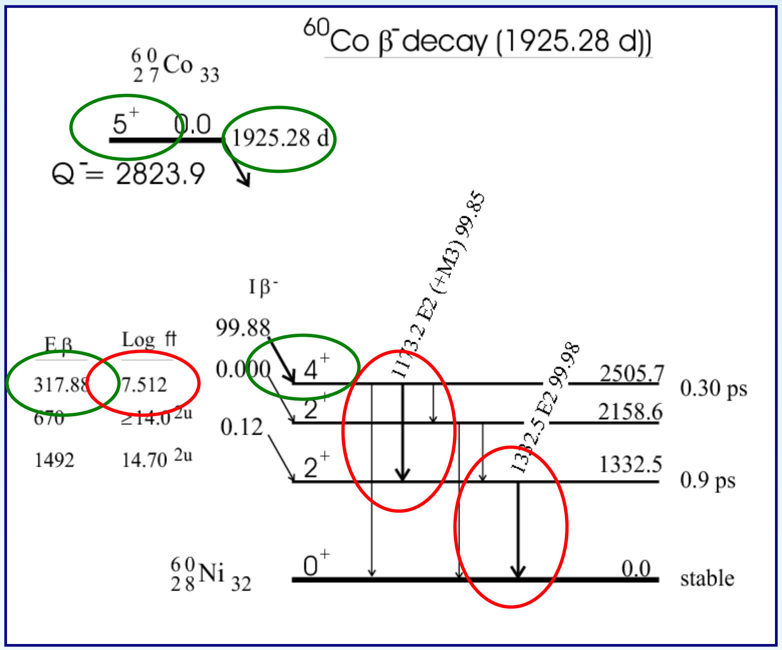
→ Simulate the complete experiment



* I. Kraev et al. , to be published in NIMA

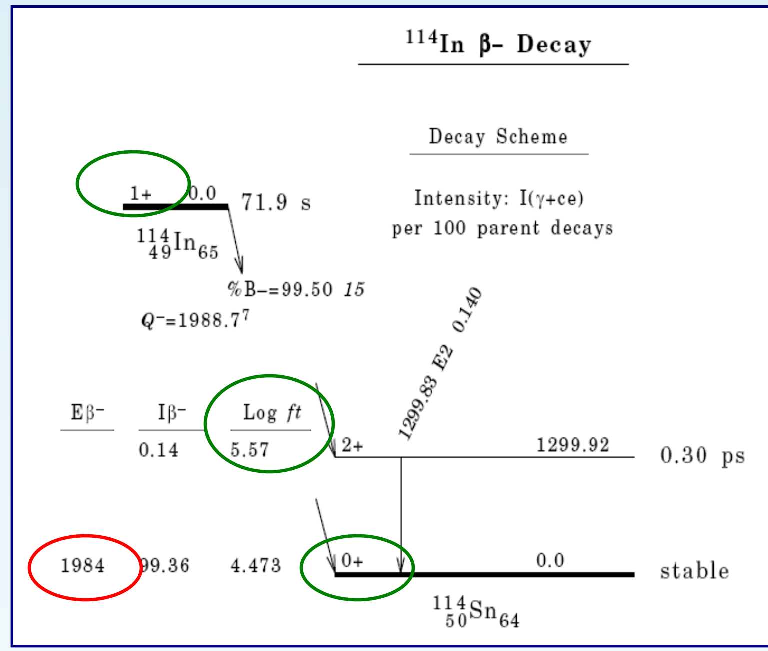
Experimental results : the β-asymmetry parameter of ^{60}Co and ^{114}In

^{60}Co



+ Low end-point → high γm/E (sensitive to C_T)
- High Log ft → nuclear corrections

^{114}In



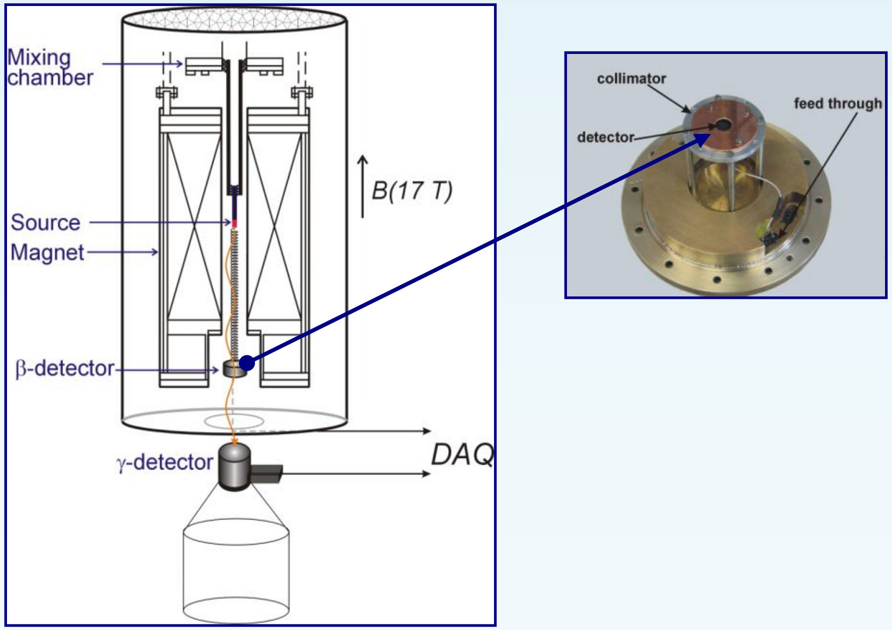
+ Low Log ft → fast clean transition
- High end-point → less sensitive to C_T

Experimental results : the β-asymmetry parameter of ^{60}Co and ^{114}In

^{60}Co

Experimental conditions

- Orientation with high external field (up to 13 T)
- Activity diffused in thin Cu foil
- Use of Si PIN diode detectors



^{114}In

Experimental conditions

- Orientation with hyperfine interactions, small external field (0,045 T, 0,09T and 0,186 T)
- Activity implanted in Fe foil
- Use of HPGe detectors

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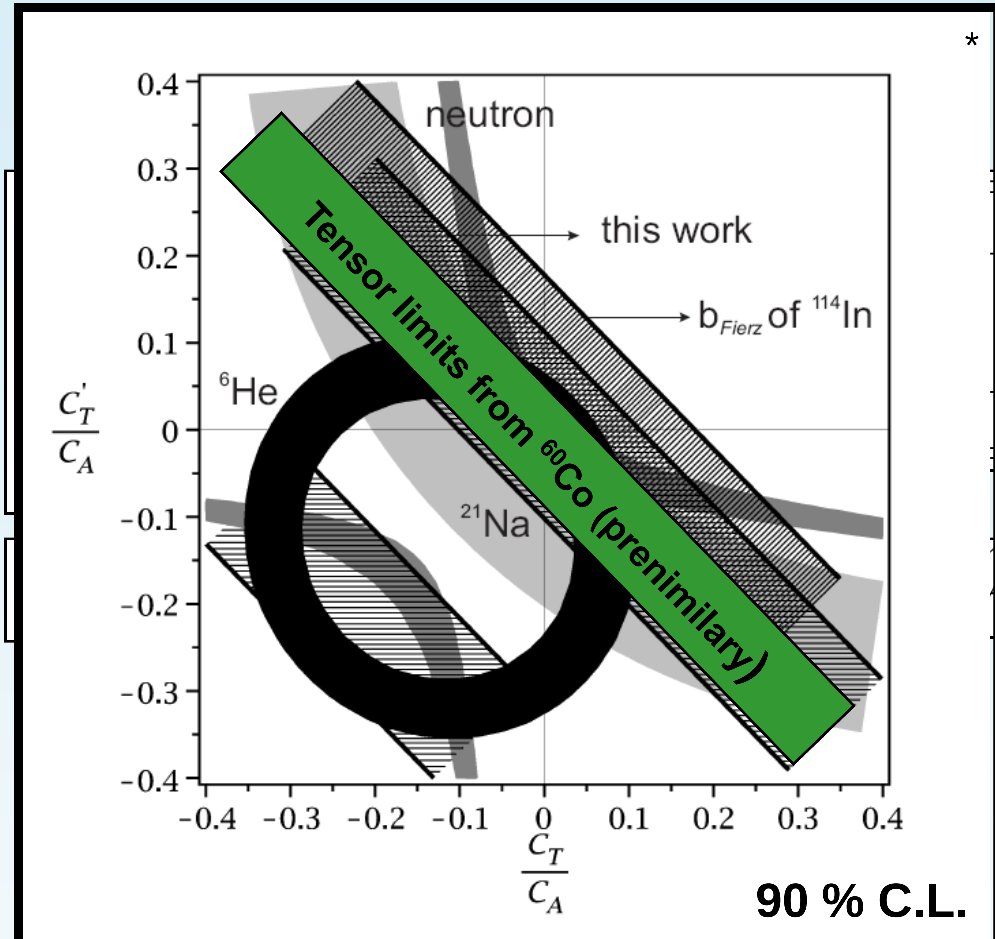
Experimental results : the β-asymmetry parameter of ^{60}Co and ^{114}In



value = -1

^{114}In

B_{ext} [T]	fraction f	$\tilde{A}$
0.046	0.734(5)	-1.003(9)
0.093	0.803(8)	-0.987(13)
0.186	0.874(7)	-0.972(11)
weighted average		-0.990(11)

$$\tilde{A} = -0.994 \pm 0.011_{stat} \pm 0.009_{syst}$$

Major sources of systematical errors :

- Sample quality (0.5%)
- Quality simulations (0.6%)
- Geometry (0.5%)

corrections were investigated (calculation by I.S. Towner) -> 0.3 % correction. Ready to extract Tensor physics.

Most precise β-asymmetry parameter for a nuclear decay.
Limits for tensor currents comparable to other single experiments

* F. Wauters et al. , to be published

Conclusions and outlook: How to get to a better precision

- Technical: Detectors working at low temperatures and in high magnetic fields.

→ Stable electronics / better (cooled) pre-amps
Thicker Si detectors (PIPS?)

- Simulations: GEANT4 code which handles electron scattering and detector response with an accuracy of at least a few percent.

→ Gain more (quantitative) control over our simulations.
Improve the input.
Investigate electron scattering.

- Physics: Most precise β-asymmetry parameter “A” for nuclear decay. Limits on $C_T^{(')}$ comparable to those coming from other single experiments, but not yet strick enough to significantly change to overall limits.

→ ^{67}Cu data (ISOLDE). Under analysis.
Look for isotopes with better sensitivity and/or smaller systematic errors.

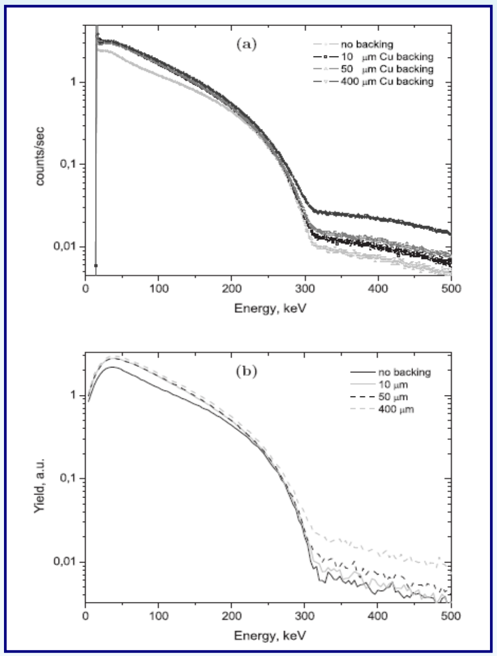
→ Further investigate possible higher order corrections *

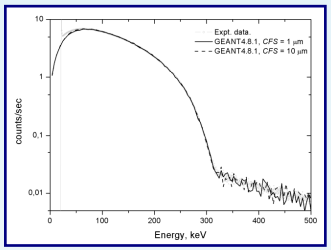
* B.R. Holstien et al. , PRC 5 (1972) 1849

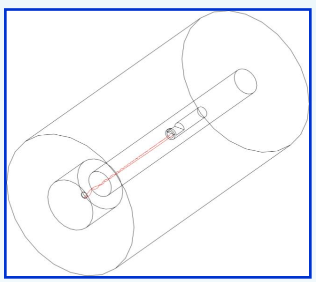
Geant4 simulations

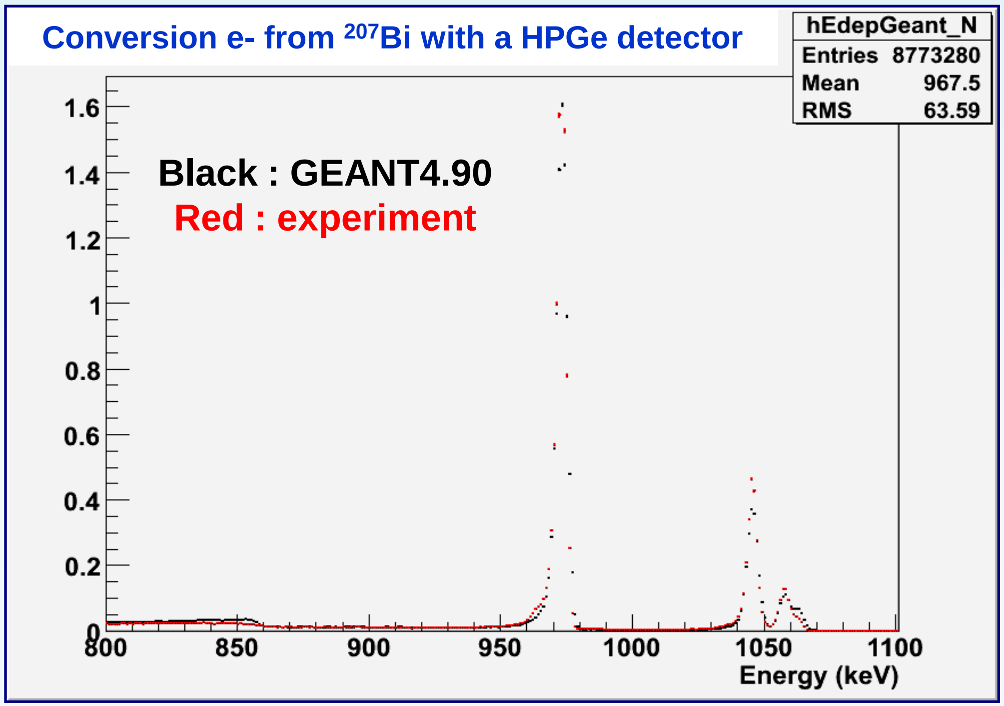
GEANT4 has to take care of scattering effects, energy loss, magnetic field effects, ...

- Use low energy packages
- Scan GEANT4 parameters to get optimal performance
- Compare GEANT4 with well controlled experimental data for *
  - → different scattering conditions
  - → different magnetic fields
  - → Si PIN diodes (done) and HPGe Detectors (ongoing)









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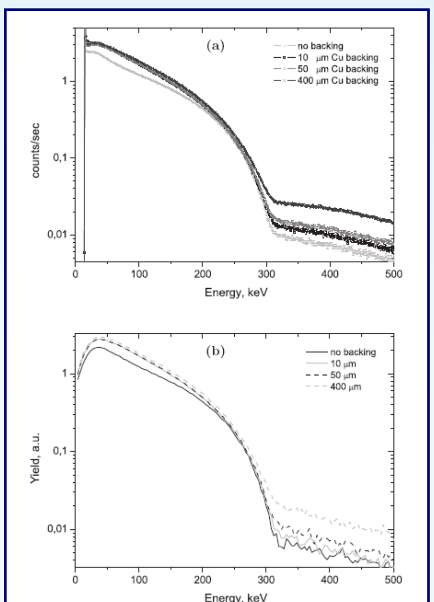

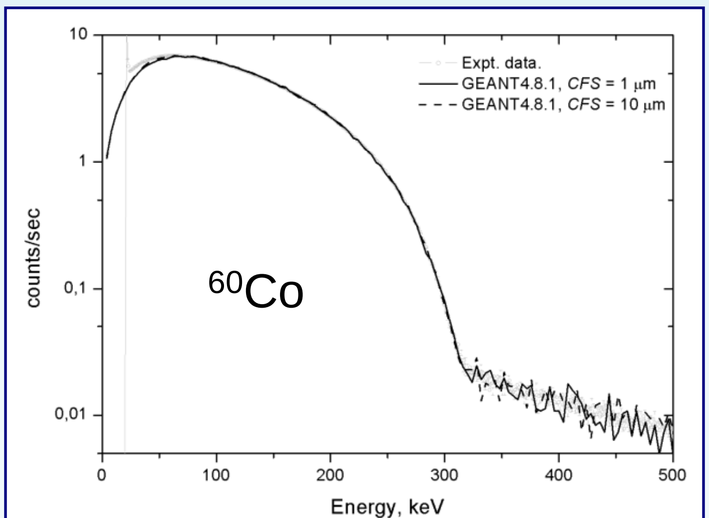

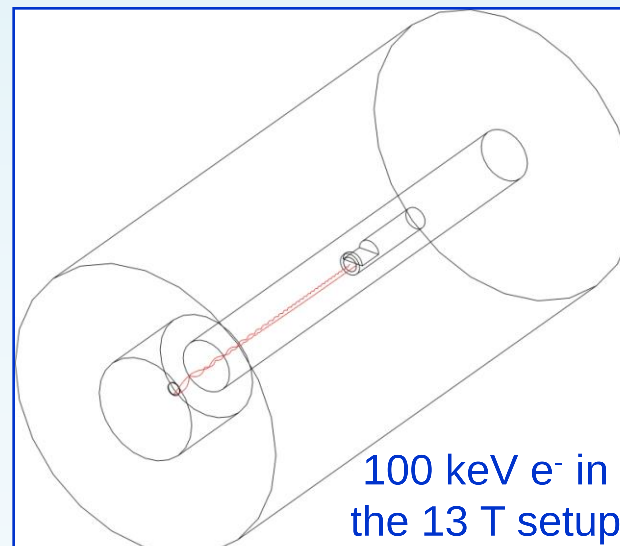

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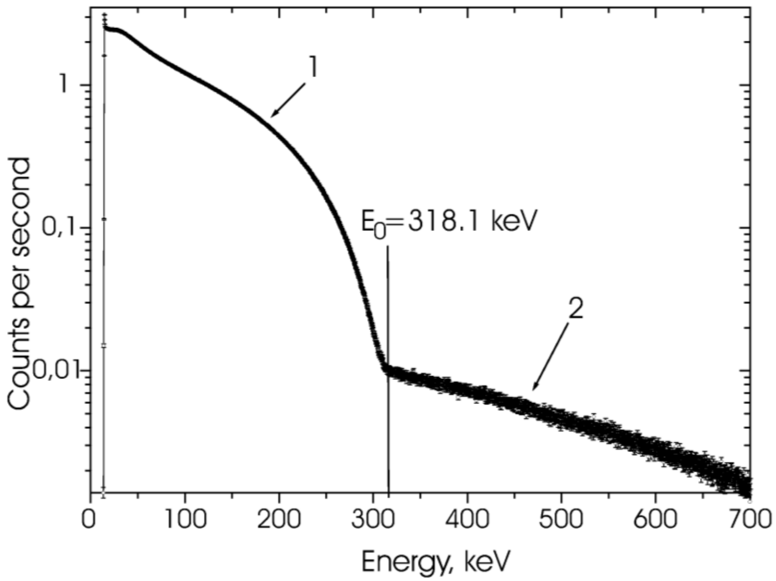
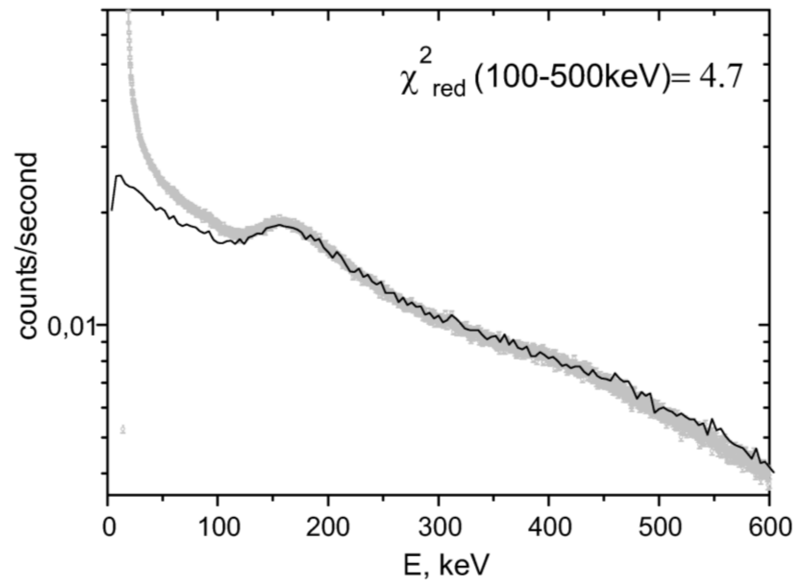
GEANT4 simulations: simple set-up 2

^{60}Co spectrum,
"scattering free" source



^{60}Co spectrum,
"scattering free" source,
detector covered by 1 mm Cu



Conclusions:

- ✓ nature of the tail: compton scattered electrons (from γ-rays of ^{60}Co)
- ✓ compton tail is a smooth function of the energy

Experimental results : the β-asymmetry parameter of ^{60}Co and ^{114}In

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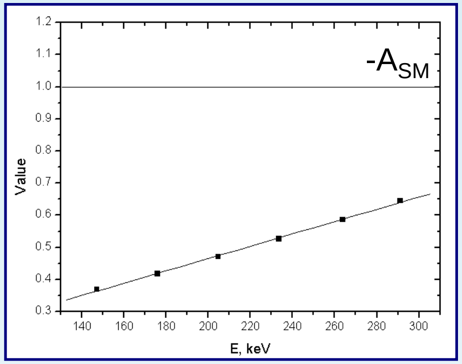
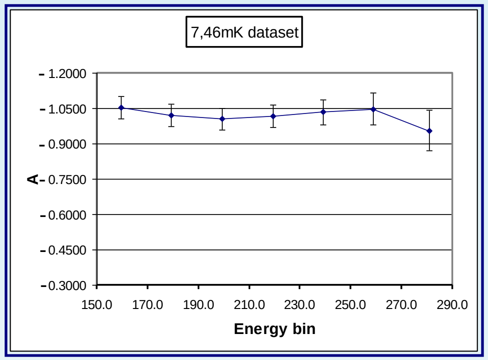
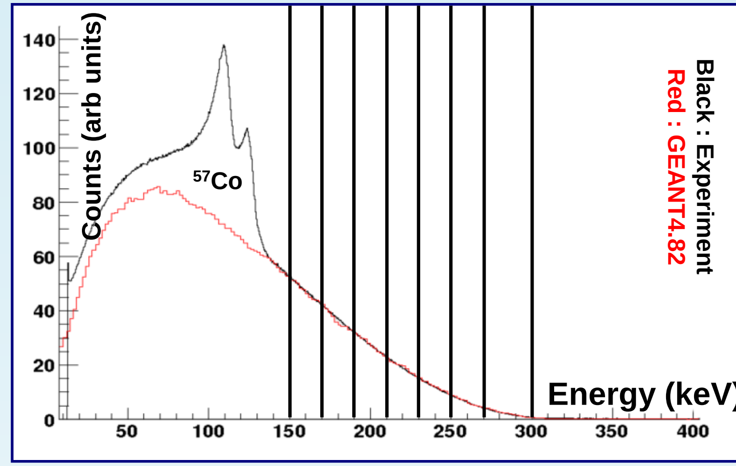
Without GEANT



With GEANT





	13 T , 7.5mK	13 T , 10.4mK	13 T , 17.1mK	9T , 7,4mK
Ã	-1.024(20)	-1.027(42)	-1.06(40)	-0,964(25)

⇓

Ã = -1,013(18) (A_{SM} = -1)

Preliminary

Error bar contribution

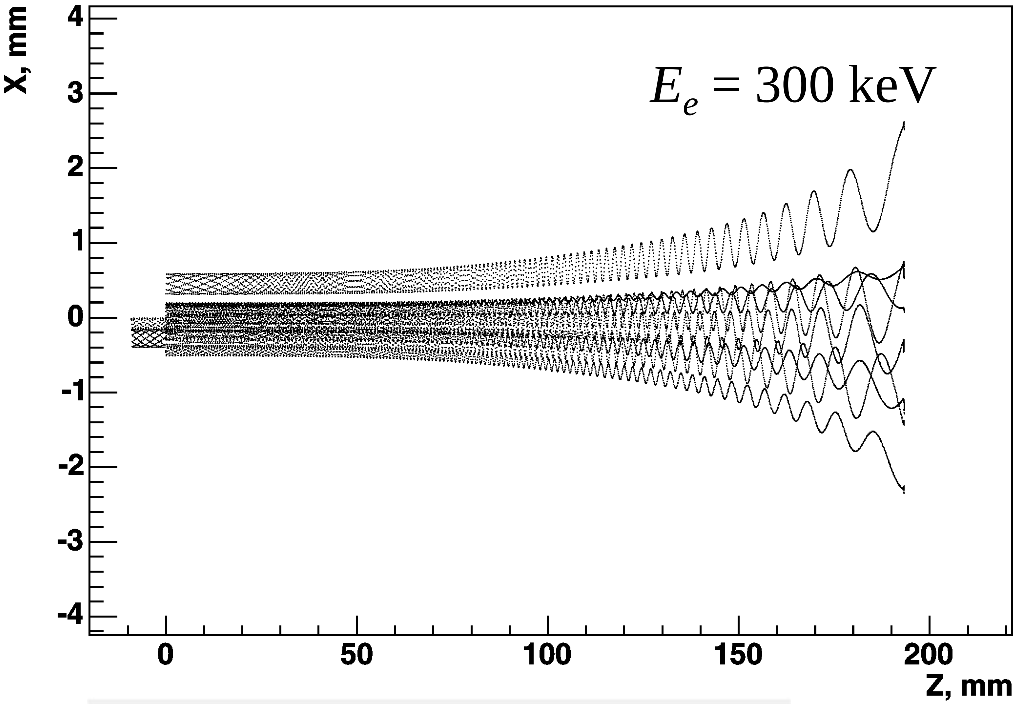
- Statistics → 1 %
- Calibration with γ`s → 0.5 %
- Quality simulations → 1.2 %
- Consistency → 0.7 %

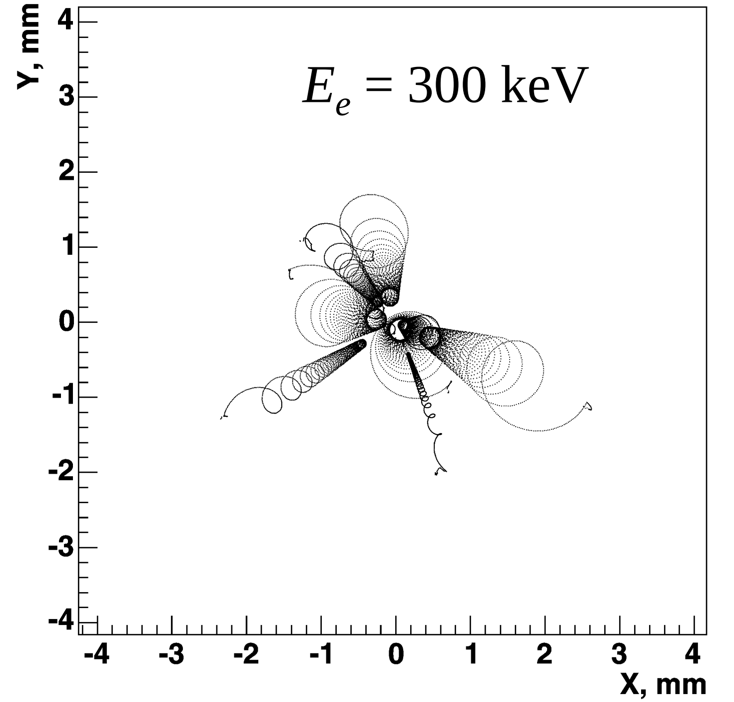
Still under investigation

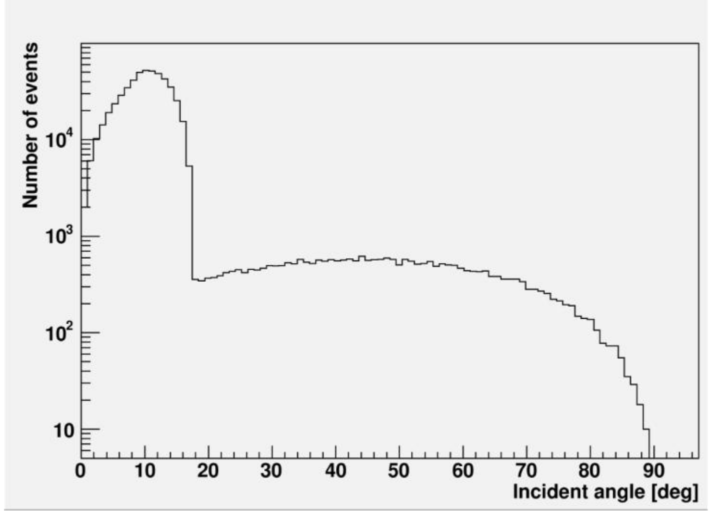
- Error compton subtraction
- Recoil corrections
- Error by choice GEANT4 parameters

* B.R. Holstien et al. , PRC 5 (1972) 1849

GEANT4 simulations: real set-up 2







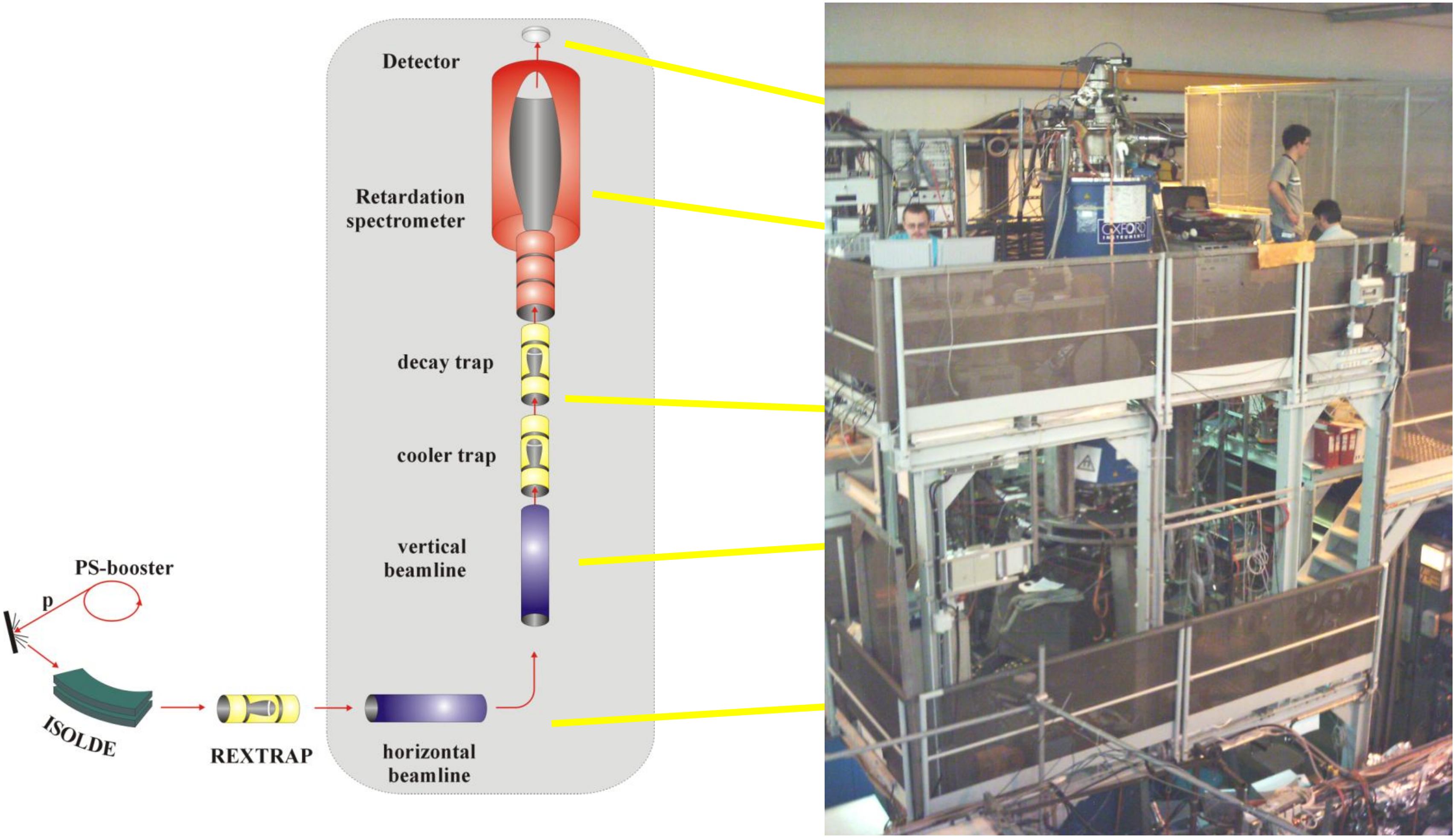
Conclusions:

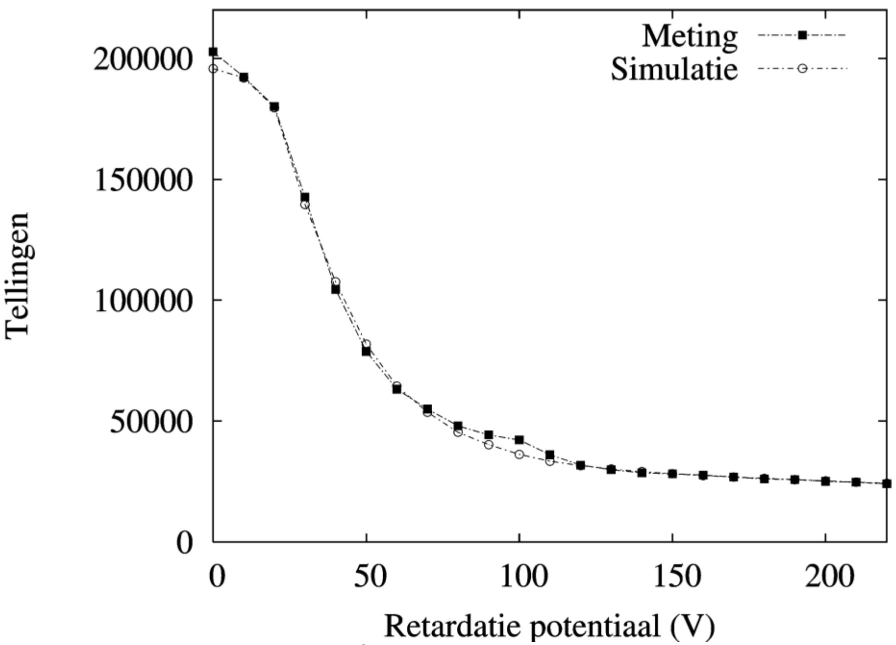
1. No scattering between the source and the detector (magnet bore ∅ = 36 mm)
2. Few events with large angles of incidence

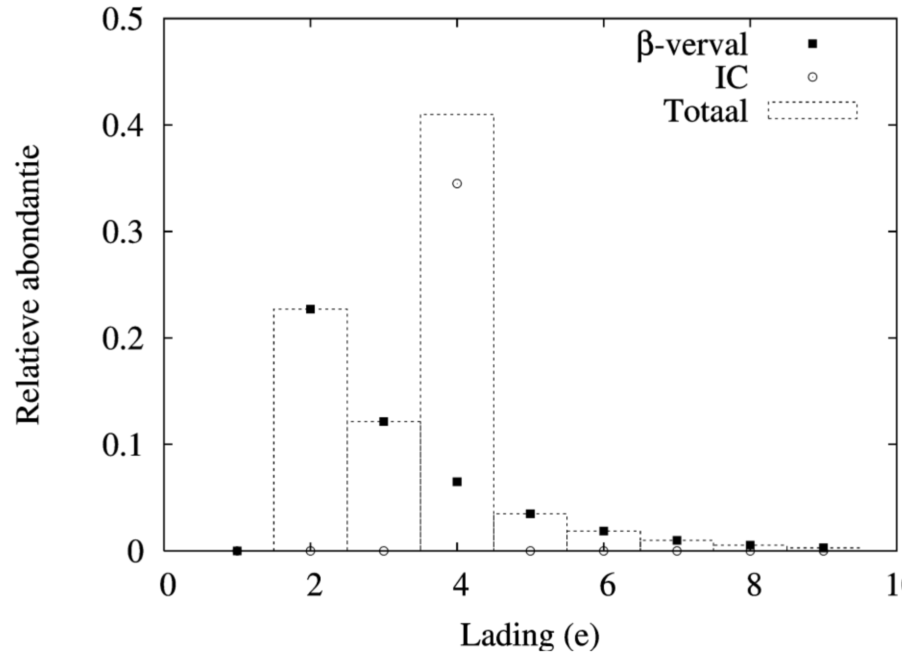
Experimentele opstelling

Weak Interaction Trap for CHarged particles

Zwakke interactie val voor geladen deeltjes







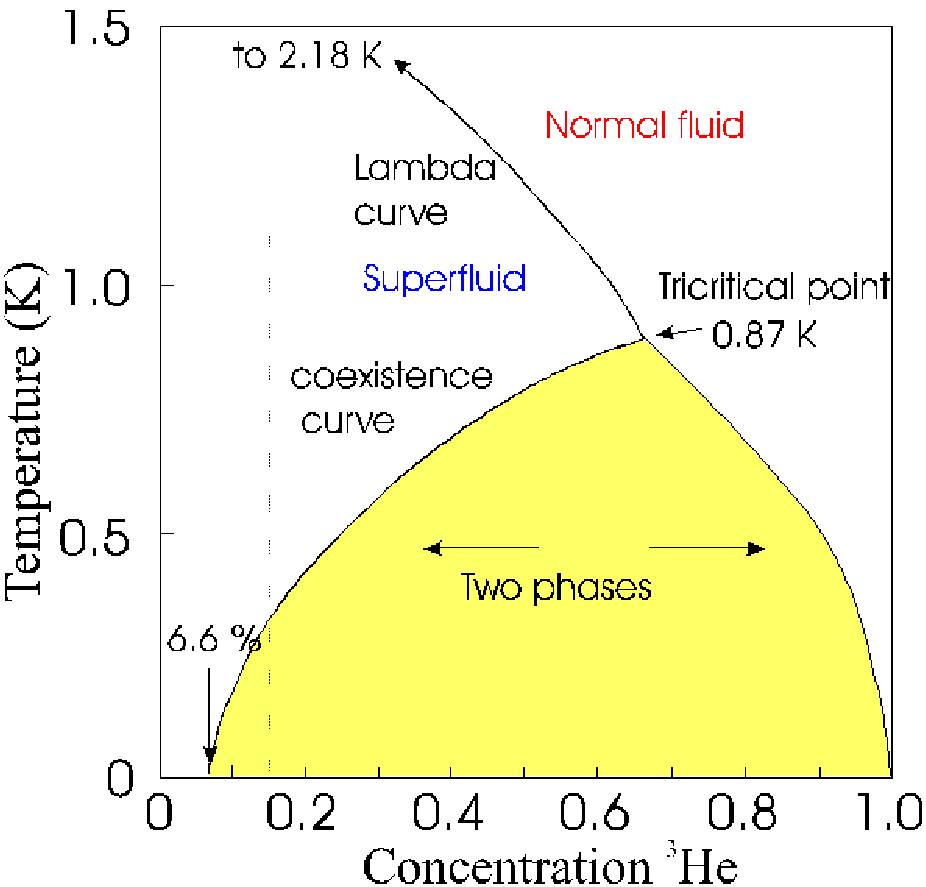
Fit parameters:

- *potentiaal offset*
- *isomeer contributie*
- *algemene schaling*
- *achtergrond schaling*

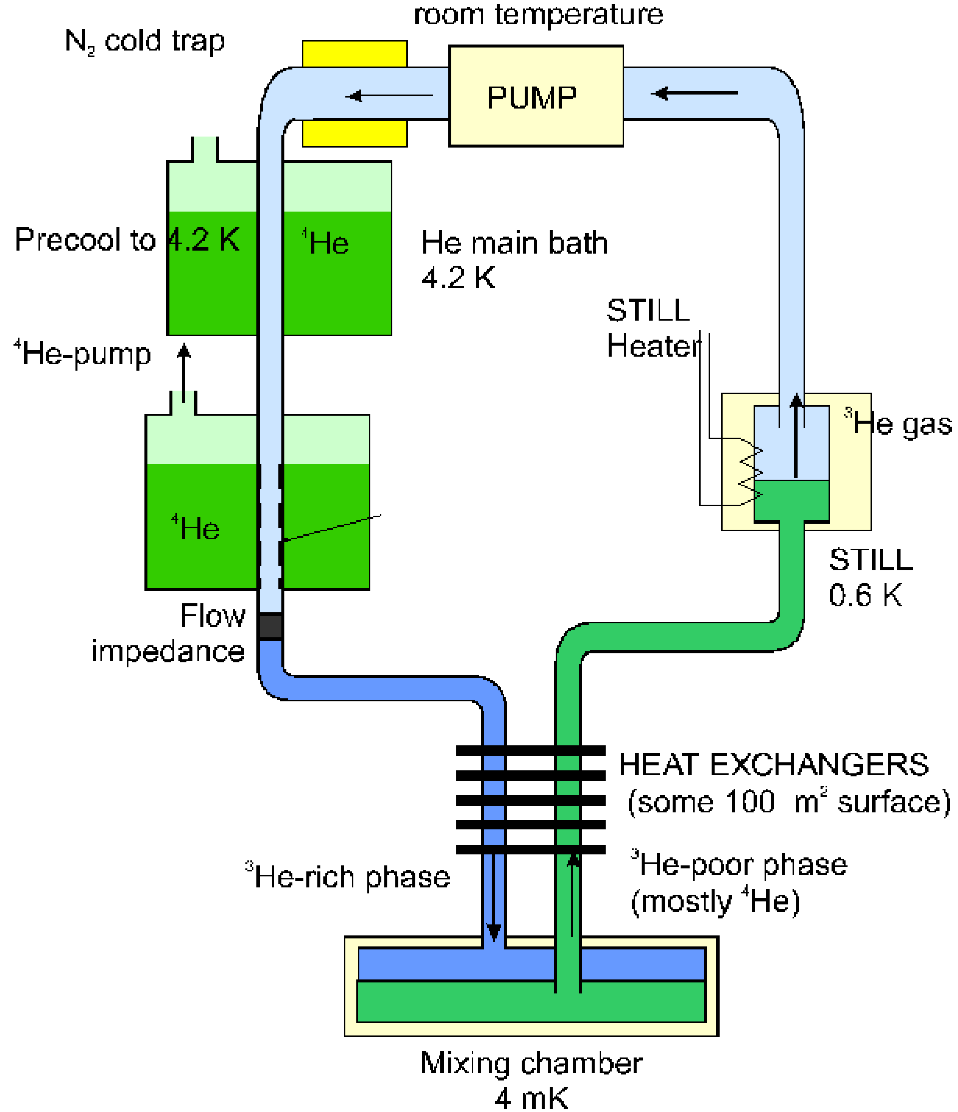
+

- *positie Auger ladingsdistributie*
- *breedte Auger ladingsdistributie*
- *helling β-verval ladingsdistributie*

Principles of dilution refrigerators

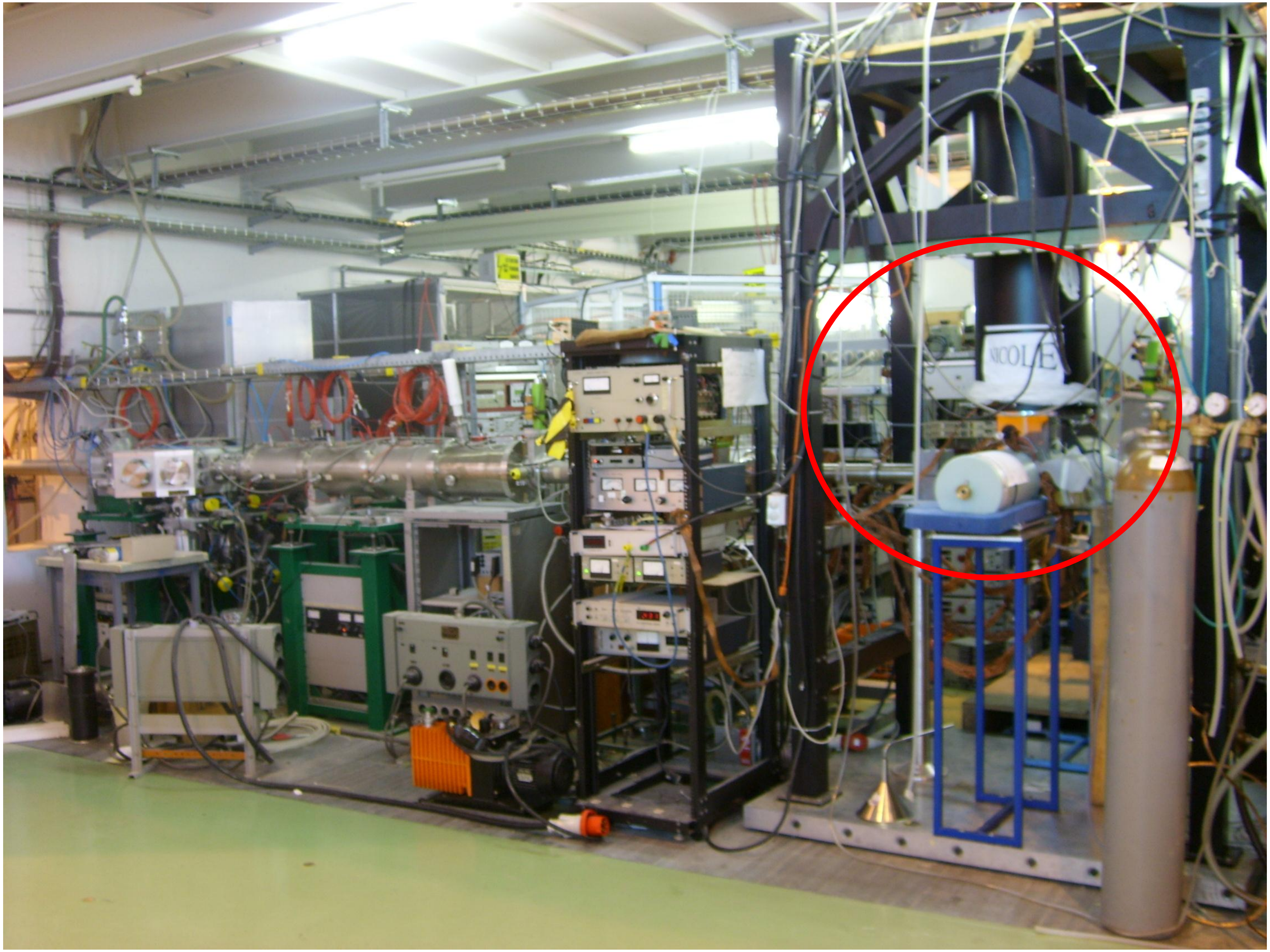


^{3}He-^{4}He Phasediagram



Off-line Nuclear Orientation

IKS - K.U.Leuven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GEANT4 simulations : Getting control over systematic effects that distort the β-asymmetry

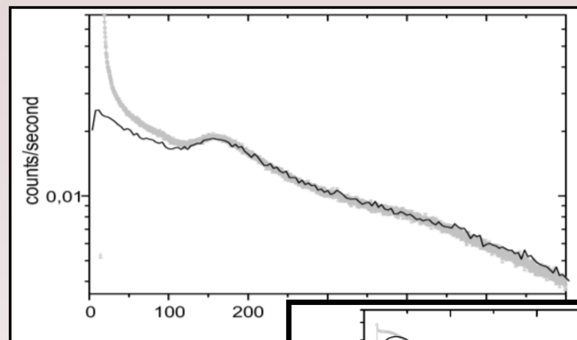
Goal: GEANT4 Monte Carlo simulations have to take care of energy losses and changes in direction of the β particle between source and detector, as well as scattering on the detector and the detector response.

What can we do?

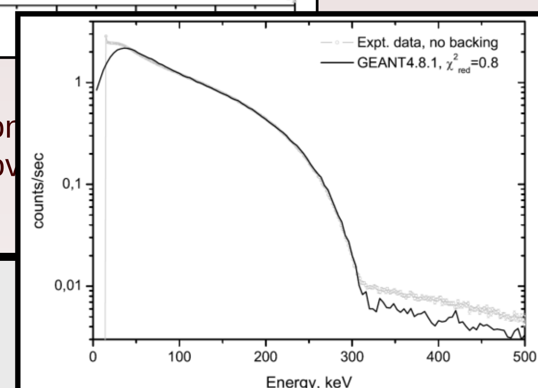
• Reproduce backscattering fractions with a relative precision of 10 % or better.
Remark : Big error on experimental scattering data

E_e, keV	This work (simul.)	Tabata[1]	Berger[2] (simul.)	Berger[2] (expt.)
250	13.2	12.9	13.2	14(1)
500	11.6	11.4	12.3	14(1)

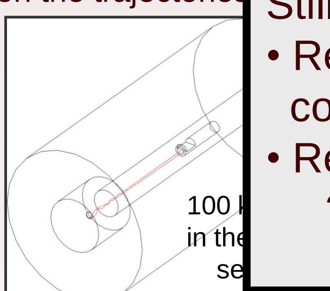
• Reproduce the shape of (compton) background

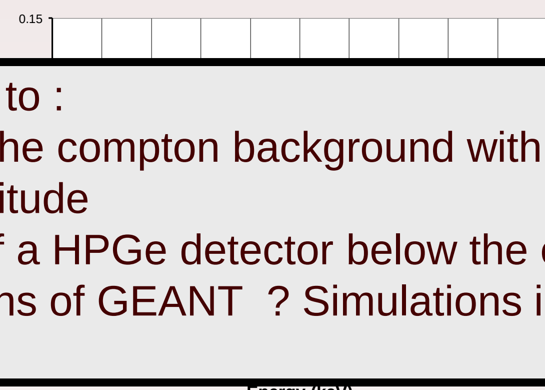


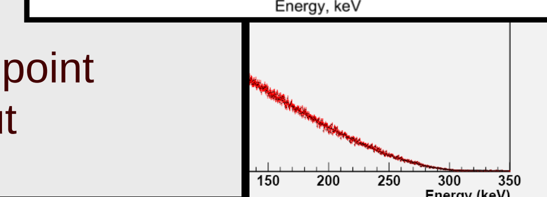
• Reproduce a cor
few percent abov



• The influence of the magnetic field on the trajectories







Still problems to :
• Reproduce the compton background with the correct amplitude
• Response of a HPGe detector below the endpoint
? Limitations of GEANT ? Simulations input